FINITE ELEMENT ANALYSIS OF TRAPEZOIDAL WEB BEAM TO COLUMN END PLATE CONNECTION

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ABSTRACT

Most structures especially the conventional steel buildings are usually using the simple design and rigid design methods. However, the actual behaviour is known to fall between these two extreme categories. The use of partial strength connections has been encouraged by studies on the matter. It is proven that it reduces the steel weight in use and thus save the overall construction cost. This project is to analyze the behaviour of trapezoidal web beam profiled to the end plate connection. Comparison between the effect of trapezoidal web beam profiled to end plate connection and stiffener is made to predict the strength, stiffness and rotational capacity of the connections. Previous research shows that the trapezoidal web beam profiled will minimize the need of stiffeners. Six models have been analyzed in this project by using LUSAS 14.0 by various type of beam. The dimension of beam is 150 x 200 x 1600 mm whereas for column is 200 x 200 x 1800 mm. The dimension for the end plate stiffener provided is 95 x 95 x 10 mm. Linear analysis is performed to obtain the deformed mesh, maximum stress and strain under axial load. In addition, a non-linear contact analysis is also done to obtain the relationship of the load-deflection at contact surfaces. The results show that the trapezoidal web beam profiled with end plate stiffener and extended end plate connection provide highest strength compared to others and with least deflection under loads.

ABSTRAK

Sambungan rasuk kepada tiang dengan menggunakan skru dan plat hujung adalah satu perkara biasa dalam sambungan kerangka besi. Kaedah separuh sambungan adalah digalakkan oleh para penyelidik dalam bidang pembinaan sebab ia dibuktikan boleh mengurangkan penggunaan berat besi dan dapat menjimatkan kos pembinaan secara keseluruhan. Projek ini adalah bertujuan untuk menganalisa perilaku pada sambungan rasuk kepada tiang dengan menggunakan plat hujung dan rasuk yang berprofil. Ujikaji yang dijalankan tentang pengaruh rasuk yang berprofil serta pengukuh kepada sambungan rasuk - tiang dengan menggunakan plat hujung untuk meramalkan kekuatannyan pada sambungan. Kajian sebelum menunjukkan bahawa rasuk yang berprofil akan meminimumkan keperluan penggunaan pengukuh. Sebanyak enam model telah dianalisa dalam projek ini dengan menggunakan perisian LUSAS 14.0. Ukuran dimensi rasuk yang digunakan dalam projek ini ialah 150 x 200 x 1600 mm dan ukuran dimensi tiang adalah 200 x 200 x 1800 mm. Manakala dimensi untuk pengukuh yang digunakan adalah 95 x 95 x 10 mm. Analisa lelurus dijalankan untuk mendapatkan bentuk jejaring, ketegasan dan keterikan maksima apabila beban dikenakan. Selain itu, analisa tidak lelurus juga dijalankan untuk mendapatkan hubungan antara beban dengan putaran sesaran pada permukaan sambungan antara rasuk dengan tiang. Keputusan kajian menunjukkan bahawa model dengan sambungan rasuk kepada tiang dengan menggunakan plat hujung dan pengukuh mempunyai kekuatan maksima dan putaran sesaran yang minima berbanding model lain.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

End plate connections were generally had a most satisfactory behaviour and have provided greater economy than could be achieved with split tee connections. A typical end plate connection consists of a plate that is shop-welded to the end of a beam which is then bolted to the supporting member in the field. There are two major types of end plate connections, there are: flush end plate connection; and extended end plate connection.

Steel beam-to-column connection comprises a web plate member and a pair of flange plate members. In this study, it connected a trapezoidal web beam to column surface. The web plate member is disposed at an end of the beam integrally formed with the trapezoidal web plate of the beam. The pair of the flange plate members are also disposed at the end of the beam and respectively integrally formed with the flange plates. As the steel beam-to-column is designed properly, they will produce strong and ductile enough when subject to earthquake loading.

Trapezoidal web beam is a type of steel section to form an I-section which use corrugated web made in trapezoidal form. The corrugated web beam is formed by a very thin web which is normally less than 10mm thickness and the web and flanges are comprised of different steel grade depending on design requirements. The thinner trapezoidal web beam section provides a higher resistance against bending and higher load carrying capacity besides more cost economical.

Finite Element Method (FEM) is a reliable tool for investigating the effect of all relevant parameters and can provide acceptable and accurate results. Besides, it is an economical method to investigate the beam-to-column connections in more detail than experimental tests would usually allow. By using the finite element analysis method, simulation of design can helps to predict errors and modification can be done at early stage before the parts was fabricated and tested. Therefore, finite element analysis method are widely be used in recent years due to its attractive means.

1.2 Problem Statement

The bolts, beam, column sections as well as the welds can all have a significant effect on connection performance. Hence, it is difficult to get an accurate analysis of a connection. If a beam is not supported in the lateral direction, the beam will fail in buckling when it is subjected to an increases flexural load to a critical limit. By using the trapezoidal web beam, it may increase the lateral torsion buckling resistance.

Due to the changes on earth surface, there are more and more areas experience the seismic effect. Therefore it is important to study the beam-to-column connection to improve its strength to seismic effect. The flush end plate connection not only provides strengthen connection between beams to column but also provide aesthetic effect. Whereas the use of extended end plate will provide an extra contact area between the beam-to-column joints and thus increase the load that the structure can stand.

1.3 Objectives of Study

The main objectives of this project concern Finite Element Analysis there are:-

i. To study the behaviour of trapezoidal web beam to column end plate connection.
ii. To compare the behaviour of flush and extended end plate connections.
iii. To compare the stiffened and unstiffened effect to the end plate connections.

1.4 Scope of Study

There are various types of connections in structural steelwork. In this study, it will focus mainly on investigate the behaviour of trapezoidal web beam to column with different types of end plate connections by using finite element analysis. An incremental load will apply at the end of the cantilever trapezoidal web beam and LUSAS software will then be used to model the connections. The result from the finite element analysis will then be compared with the existing experimental result.

1.5 Significant of Study

Research significance to be obtained from this study will be the results and analysis of the behaviour of beam-to-column end plate connections, when extended end plate or flush end plate and corrugated web beam is used. It is necessary to compare the moment rotation curve of the result from the finite element analysis and experimental testing. Besides, the effects of stiffened and unstiffened effect to the trapezoidal web beam-to-column connection are also necessary to take in consideration. The aim was to determine the accuracy of the analytical method and to verify the strength of the corrugated web beam as compared to a plane web. Trapezoidal web beam is still new in the industry, so if much research is done on it, more application of it can vary our steel industry products.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Beam-to-column connections are important elements of a steel frame and their behaviour influenced its performance under the load. Therefore, the classification of joints as well as their behaviour will be discussed in this chapter.

2.2 Beam-to-Column Connection

Beam-to-column connection can be identified by understanding the behaviour characteristics of the particular connection. Conveniently, these behaviour characteristics can be represented by a relationship between the joint moment and the rotation of the connected member. This useful and important relationship can be depicted by a curve called moment-rotation curve (M-Φ curve). Based on the moment-rotation curve, a connection can be classified as full strength and partial strength connections.

2.3 Full Strength Connection

A full strength connection is defined as a connection with a moment resistance at least equal to the moment resistance of the beam (Allen et. al., 1994). A plastic hinge will be formed in the adjacent member, but not in the connection as shown in Figure 2.1, case A. In this case, the plastic rotation supply depends on the width-to-thickness ratios of the plate elements constituting the beam section. However, due to the beam strain-hardening, the connection degree of over strength could not be sufficient to prevent connection yielding as shown in Figure 2.1, case B. In such a case, yielding can occur at both the beam end and in the fastening elements. In addition, only a part of the beam plastic rotation capacity can be exploited, so that the plastic rotation supply of the connection becomes of primary importance (Kukreti et. al., 1987).

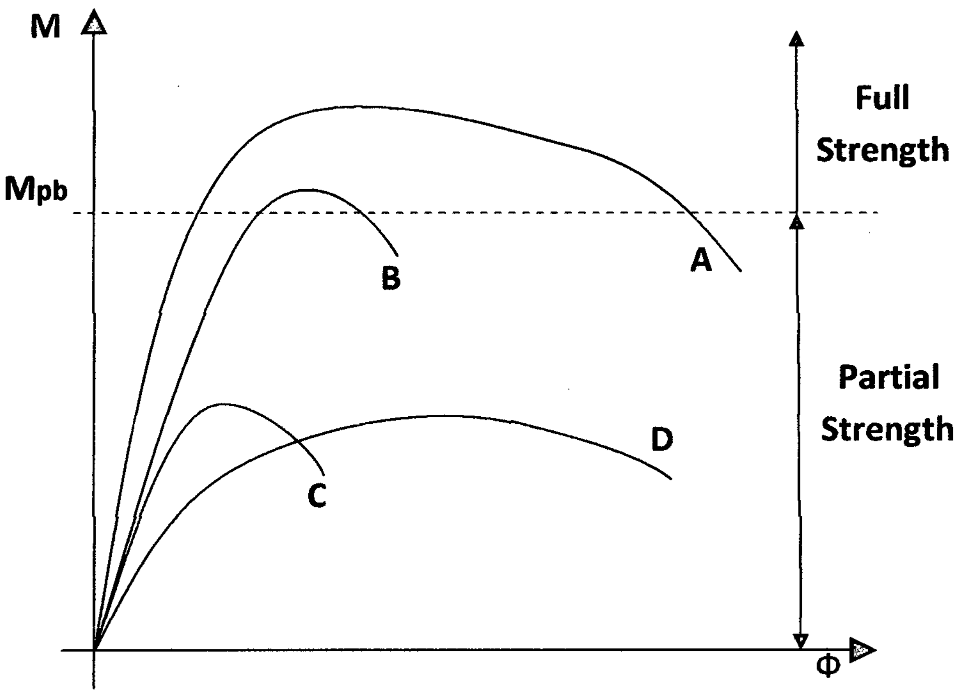


Figure 2.1: Beam-to-column joint classification according to their flexural resistance.

2.4 Partial Strength Connection

A partial strength connection is defined as a connection with moment resistance less than the moment resistance of the connected beam member for both case C and D in Figure 2.1. A plastic hinge will be formed in the connection; in such case, sufficient rotation capacity is required as shown in Figure 2.1 for case D. It means that for case C as shown in Figure 2.1 is unsuitable, because its rotation capacity could be exceeded under design loads.

According to Tahir et. al.(2006), the advantages of the partial strength approach are that it utilises the moment resistance of connections to reduce beam depth and weight, while avoiding the use of stiffening in the joints. This practice will reduce the cost of fabrication and ease the erection of steel member in the construction of multi-storey steel frames. The potential benefits of using partial strength connection are as follow:-

i) Lighter beam

In the design of semi-continuous braced steel frame, the required beam plastic modulus is less than those required in simple frame for the same frame. This reduction is possible as the partial strength connection reduced the design moment of the beam due to the partial restraint effect to the connection. The design moment which a beam must resist, decreases as the moment capacity of the connection increases. As a result, a lighter beam can be selected for the design of the beam.

ii) Shallower beam

The partial restraint of the connection will also result in shallower beams. This is due to the increase in stiffness of the connection, which contributes to the decrease in deflection. The partial strength connection acts as restrained to the deformation of the beam due to applied load. As a result, a reduction in the deflection of the beam can be achieved which lead to the shallower beam.

iii) <u>Greater stiffness and more robust structure</u>

Connection rotational stiffness means that the ends of a beam are restrained against rotation. Partial strength connection has higher capacity to restrain against rotation, shear, moment and tying force compared to pin connection. The shear capacity of the connection is designed at higher shear capacity of the connected beam, and the moment capacity of the connection can resist up to 50 % of the moment capacity of the connected beam, depending on the size and number of bolts for the proposed standard tables. Therefore, the connection can be categorised as strong, stiff, and robust.

iv) <u>Lower overall cost</u>

According to Allen and Mike (1992), the saving in the overall cost can be achieved due to the following reasons:-

- A reduction in the number of connection types may lead to a better understanding of the cost and type of connection by all steel players such as fabricator, designer, and erector.
- A standardised connection can enhance the development of design procedures and encourage in the development of computer software.
- The use of limited standardised end plates or fittings can improves the availability of the material leading to reduction in material cost. At the same time, it will improve the order procedures, storage problems and handling time.
- The use of standardised bolts will reduce the time of changing drills or punching holes in the shop which lead to faster erection and less error on site. The drilling and welding process can be carried out at shop, as the geometrical aspects of the connection have already been set. This leads to fast and quality fabrication.

2.4.1 End Plate Connection

End plate connection is one of the types of partial strength connection that commonly in used. It is widely used in constructional steel design due to its great variety of structural solutions, ranging from quasi-pinned connections to rigid connections, by properly modifying the connection structural detail. In particular, both the rotational stiffness and the flexural resistance can be properly balanced by choosing an appropriate number of bolts and their location, an appropriate end plate thickness and its geometrical configuration and, finally, a stiffening detail for the column panel zone.

The early finite element analysis of moment and plate connections is conducted by Krishnamurthy (1979). This study included thirteen finite element models of "benchmark connections, with dimensions spanning values commonly used in the industry". A two-dimensional and three-dimensional finite element analysis was conducted to determine adequate correlation between results. But due to the limited technology of that time, some assumptions were made so that a three-dimensional model was created based on a constant strain triangle and eight-node sub parametric brick elements. Krishnamurthy had concluded that prying forces do not exist in moment end plate connections at end of his paper.

Grundy et. al. (1980) conducted two tests on extended end plate connections with two rows of four bolts (eight totals) at the tension flange. A procedure for the design of beam-to-column connections is presented in the paper. The bolt forces include a 20 % increase to the direct force to account for prying action.

End plate connections can first be divided into two groups, on the basis of the bolt location, which known as:-

i. extended end plate connection
ii. flush end plate connection

2.4.1.1 Extended End Plate Connection

Extended end plate connections are characterized by the presence of at least one bolt row outside the beam flanges. Therefore, there are usually divided into one-side extended end plate connection as shown in Figure 2.2 (a), which are commonly used in frames withstanding vertical loads only; and two-side extended end plate connections as shown in Figure 2.2 (b), which also can be used in frames subjected to both vertical loads and horizontal forces, due to the wind action or to the seismic motion.

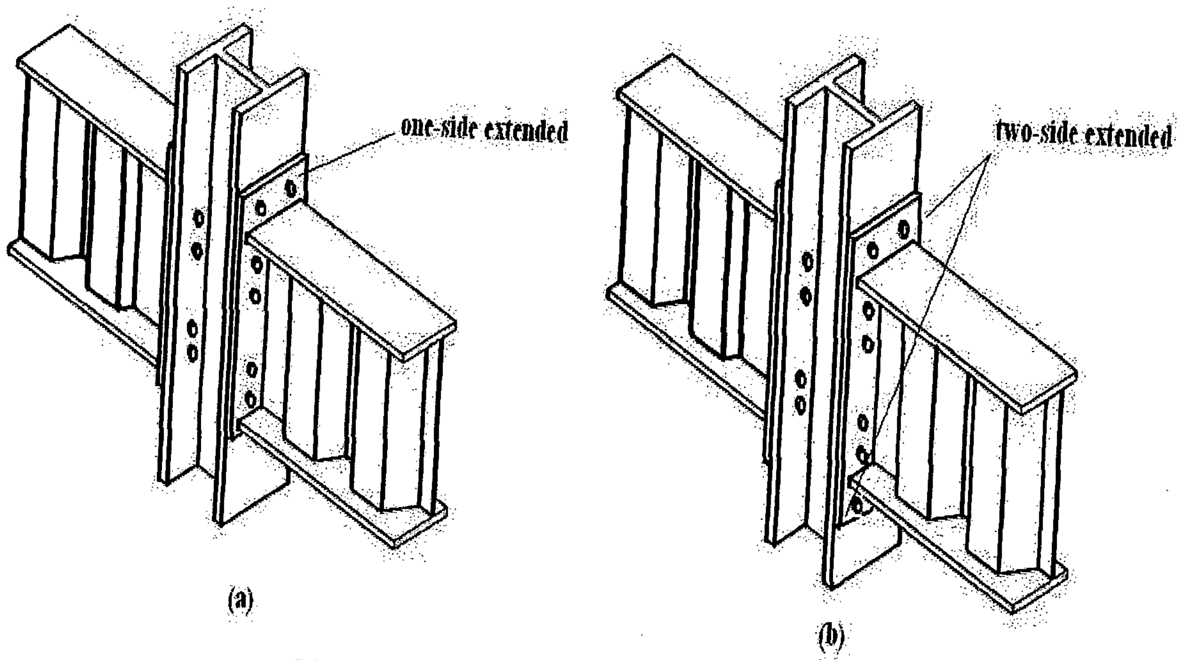
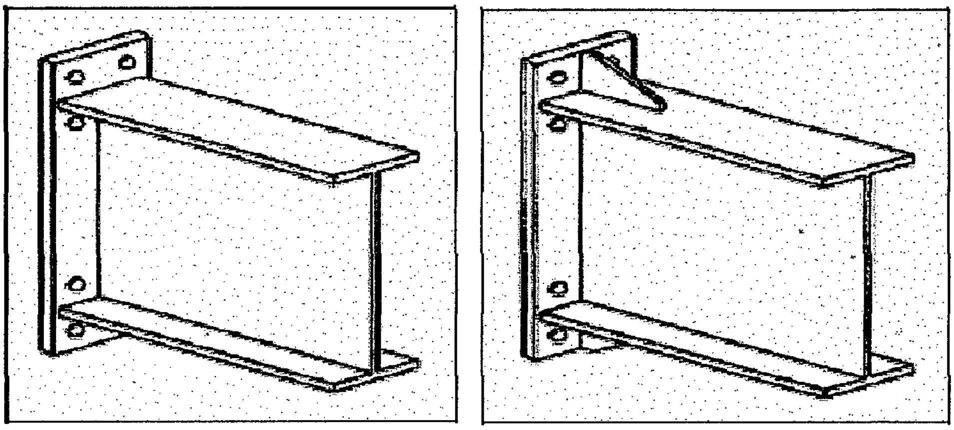


Figure 2.2: Extended end plate connections.

Extended end plate is used in situation where it is necessary to transfer substantial moments from beam to columns, the extended end plate, with a row of tension bolts outside the beam flange is the most popular solution.

Extended end plate can be unstiffened as shown in Figure 2.3 (a) or stiffened as shown in Figure 2.3 (b) too. The stiffened configuration has gusset plates as stiffener welded to the outside of the beam flange and to the end plate. The stiffener is aligned with the web of the connecting beam to strengthen the extended portion of the end plate.



(a) Unstiffened (b) Stiffened

Figure 2.3: Unstiffened and stiffened end plate connections.

Chasten et. al. (1992) conducted seven tests on large extended unstiffened end plate connections with eight bolts at the tension flange (four bolts wide). Bolt snug and fully tensioned bolts were used in the testing. End plate shear fractures, bolt fractures, and weld fractures were the observed failure modes. Finite element modelling was used to predict the distribution of the flange force to the tension bolts and to predict the magnitude and location of the prying force resultants. It was shown that the end plate shear and bolt forces, including prying, can accurately be predicted using finite element analysis. In addition, simple design rules that complement the existing procedures are presented.

2.4.1.2 Flush End Plate Connection

A typical flush end plate connection comprises a rectangular steel plate of nearly the same depth as the depth of the beam, which is welded to the end of a beam (B. Bose et. al., 1997). This assembly is connected to the flange of a column by one or two pairs of high-strength steel bolts located near the beam tension flange and a pair of bolts near the beam compression flange as shown in Figure 2.4.

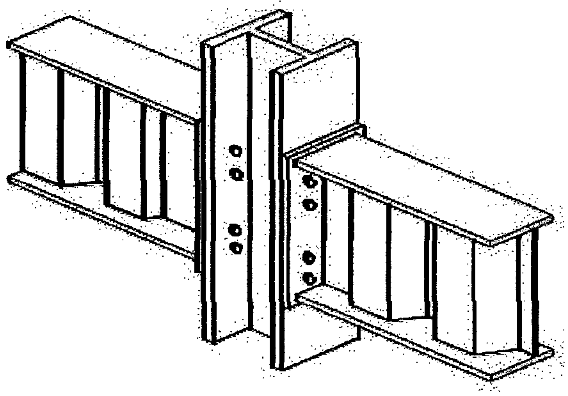


Figure 2.4: Flush end plate connection.

Borgsmiler et. al. (1995) conducted five tests on extended end plate moment connections with large inner pitch distances, the distance from the inside of the flange to the first row of inside bolts. Results showing the end plate, bolt, and connected beam behaviour were presented.

Two full scales testing with beam set-up as sub-assemblages and beam-to-column connection set-up as flush and end plate connections have been carried out by Tahir et al. (2008). It was concluded that the use of extended end plate connection has contributed to significant reduction to the deflection and significant increase to the moment resistance of the beam than flush end plate connection.

2.5 Trapezoidal Web Profiled Steel Section

The trapezoidal web profiled used in this project is Lysaght Spandek®. This trapezoidal web profile plate girder is a built-up section made up of two flanges connected together by a thin corrugated web usually in the range of 3 mm to 8 mm. Even the thickness of the trapezoidal web beam is relatively thinner compared to the common flat web beam, but it provides higher strength and can sustain higher capacity of load.

Robert et al. (2006) indicated that the weight of plate beam with corrugated webs can be 30% less than the weight of plate girders with flat webs with the same static capacity. However, since bridges represent prime candidates for the use of such beam due to the significant reduction in material and labour costs, then the fatigue testing and analysed would be more relevant to evaluate the behaviour of the beam.

Zhang et al. (2000) studied on the influence of the corrugation parameters and developed a set of optimized parameters for the wholly corrugated web beams based on the basic optimization on the plane web beams. It was also found that the corrugated web beam had up to 2 times higher buckling resistance than the plane web beam.

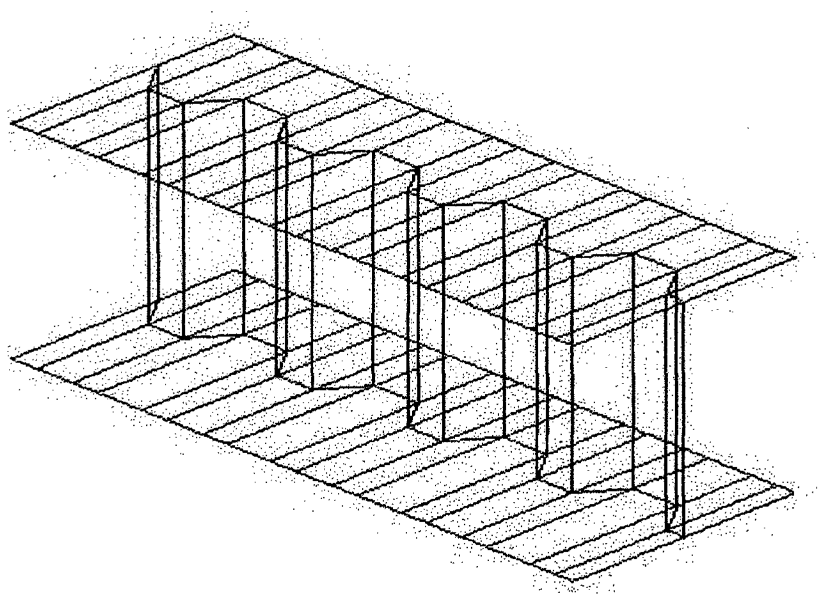


Figure 2.5: Trapezoidal web profiled steel section.